Motion Feedback 101:

Select the Right Feedback for Your Application by Knowing the Basics

Learn the environmental, electrical, and mechanical considerations you'll need to take into account to choose the right feedback device for your application.

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If there's any one truism in engineering it is that there's no one perfect solution – there's only the best solution for the application at hand. When it comes to feedback devices, OEMs have a wide range of options. Should you use a resolver or an encoder? If you need an encoder, should you opt for an optical or magnetic device? Should you select an Incremental or absolute encoder? What is the most appropriate mounting configuration? Do you need ingress protection (IP), and if so, to what level? How about resolution? The sheer variety of choices can be overwhelming, but while you're well advised to work closely with your vendor to make a final decision, there are a few environmental, electrical, and mechanical considerations that can help you narrow down the right feedback options for your system.

Environmental Considerations: Feedback Type

First and foremost, you need to thoroughly understand your application and the circumstances under which the system will operate. Start with the environmental conditions. A system will be exposed to very different conditions in a cleanroom than in a sawmill, in an MRI machine than in a bottling plant. The base-level conditions govern one of the most fundamental choices you need to make: Should you use a resolver or an encoder?

A resolver is a highly simple, inherently absolute position-feedback device. It's basically a special type of rotary transformer that consists of a stationary stator and a rotor that moves with the load. Voltage from the input winding couples to the output winding with a magnitude that varies as a function of angular position. Because resolvers do not require onboard electronics, they can tolerate harsh conditions such as temperatures up to 200 °C, elevated radiation levels, contamination, and high shock and vibration. They're analog devices that provide a continuous signal over a full rotation, corresponding to essentially infinite resolution. For a range of high-reliability applications in difficult environments like aerospace, steel manufacturing, and glass fabrication, a resolver is far and away the best choice.

Unfortunately, the downside to the resolver also lies in the fact that it's an analog device. Although it does not require onboard electronics, the electronics needed to convert signal into digital output have to go in the system somewhere, typically on the drive. Executing the electronics requires a certain level of knowledge at the design and installation level. They won't necessarily be a good fit for all designers or all customers.

Less demanding applications that put the focus on simplicity are probably better served with an encoder. Encoders can be classed as optical or magnetic. Both involve the same overall design concept, although executed using different sensing mechanisms that interact with the environment in two very different ways. In an optical encoder, a patterned disk that turns with the motor shaft essentially acts as a chopper to modulate the beam from a fixed LED as it passes through to a fixed photodiode. The photodiode converts the optical pulse train into a series of electrical pulses that can be processed to yield position or speed data.

Although with today's technology there are exceptions to nearly every rule, in general, optical encoders deliver better resolution than magnetic versions – as much as 10,000 pulses per resolution (PPR) for incremental designs using direct read and over 1×106 PPR for absolute versions (more on that distinction later). Optical encoders tend to be economical, using simple optoelectronic components, often integrated at a chip level that allows them to take advantage of the economies of scale afforded by batch processing. Higher resolutions require tighter manufacturing tolerances, however, which can drive up price. A bigger problem is that optical systems are vulnerable to contamination. Dust, dirt, and even water vapor can cause scattering, while greases and other liquids can impair the optical surfaces, all of which attenuates the signal. Meanwhile, LED output tends to drop as the devices age, a process accelerated by high temperatures. Shock and vibration can also be a problem.

Magnetic encoders provide an alternative. Operating analogously to optical encoders, magnetic encoders use rings or drums patterned with alternating magnetic domains. As the drum turns with the motor shaft, the magnetic field detected by the readout circuitry varies, again generating a series of electrical pulses. Because the designs do not require optical transmission, they're very robust with respect to contamination. In paper mills, for example, magnetic encoders can operate accurately while coated with an inch of dust. They can be covered with oil, immersed in water, and shaken until they rattle; such conditions will not affect performance

The trade-off for this robustness is somewhat lower resolution. In addition, magnetic encoders don't tend to be good fits for applications exposed to high magnetic fields, such as those found in MRI machines.

What to know before you call

1. *What are the special environmental conditions, including temperature, contamination, radiation exposure, shock, and vibration?*
2. *The level of resolution do you need?*
3. *Do you need absolute position information or can you afford to re-home at startup?*
4. *What are your budget constraints?*
5. *What is the skill level of your design/installation team?*
6. *What is the skill level of your customer in terms of maintenance and tuning?*

Electrical Considerations: Incremental vs. Absolute

It doesn't matter how well a particular encoder type can stand up to environmental conditions if it doesn't supply the type of feedback required by the application. Resolution, of course, is key. A pick-and-place arm that needs to position electronic components to micron-scale accuracies won't perform as required if the feedback doesn't offer sufficient resolution. At the same time, a hydraulic door on a warehouse loading dock probably only needs to be accurate within a matter of an inch or so, in which case high-resolution feedback introduces unnecessary cost.

Feedback type may be just as important. Encoders can be classified as incremental or absolute. An incremental encoder, whether optical or magnetic, monitors the number of counts traveled from some home position established at startup, whereas an absolute encoder outputs location in the form of a digital word. In the event of a power interruption, an incremental encoder would need to be re-homed in order to acquire its location whereas absolute encoder maintains a record of its absolute position at all times. For a packaging machine that is started up daily and can easily be re-homed in the event of a fault, an incremental encoder can provide an economical solution. In the case of a surgical robot, rehoming after loss of position could endanger patients and medical staff alike, making an absolute encoder the better choice.

The simplest incremental encoder may have only a single channel with a set number of pulses per revolution, perhaps with the addition of a single-pulse index channel that can be used to establish home position. These types of designs can only track displacement, not direction. A single-channel encoder is effective in a basic conveyor positioning applications where product is detected at a location and the encoder pulse train is used to count and then initiate an automated operation like date code printing. A single-channel encoder can be a good fit for simple speed applications like a material payout via an auger conveyor since the motor essentially only turns in one direction and dynamic requirements of the system such as torque and speed can easily be accounted for when selecting the motor and encoder.

Most positioning applications need to monitor direction. In such cases, quadrature incremental encoders provide a better fit. A quadrature encoder consists of two or more channels that are 90° out of phase (in quadrature) with one another. Because of this phase offset, one signal from channel goes high before the other, allowing the system to always track the direction of motion.

This capability provides benefits beyond just positioning information. A single-channel encoder might misinterpret feedback from an axis dithering about a set position, potentially causing oscillations that at best increase settling time and at worst introduce error. A quadrature encoder can recognize the phenomenon and filter it out as noise, allowing the system to more rapidly settle to the desired position.

In general, incremental encoders cost less than absolute encoders. They also tend to provide a wider range of choices in terms of mounting styles. They're a good fit for applications with forgiving performance parameters. When it comes to systems that require high uptime or extremely accurate performance, however, an absolute encoder may be the most effective solution for the money.

Absolute encoders simplify operation. Multi-axis systems involving any but the most simple point-to-point motion must establish references between axes. An incremental encoder requires the system to establish that reference each time it is used. In the case of an absolute encoder, that process needs to be completed one time only, during integration. Once that takes place, the system is set up for the duration, with minimum startup time. That means that a system with absolute encoders will have more uptime than one without. Absolute encoders also offer a greater margin of error. As system complexity rises, errors, faults, and downtime increase. Parts don't always wind up in the right spot, especially during set up or changeovers. Choosing an absolute encoder removes one more error source.

Absolute encoders are good solutions for electronic line-shaft applications like high-speed printing that require multiple axes to work in tandem or be synchronized in some way. Such systems require registration among the different colors, so the operator needs to be able to dynamically tune the shaft rotation mid run. That's really best done with an absolute encoder, where referentially the numbers can be sequenced to each other. In these applications, the higher resolution capability of absolute devices more accurately establishes the position being controlled. The result can be near-zero position error, which translates into a higher quality product and reduced wear on the mechanical components of the machine.

No engineering project can stray far from the cost conversation for long, of course. Absolute encoders feature more complexity, which means that they're generally more expensive than incremental designs. That said, frequently the differential between the two constitutes just 1 or 2% of the overall system price. For a number of critical applications, the improved availability, coupled with the savings in downtime and cost of operations, offsets the increase.

Mechanical Considerations: Mounting Types

At this point, we've narrowed down the feedback type to one that will survive the conditions of the application and that will provide the type of input necessary to deliver the performance required. Now, designers need to think about how the component will integrate into the system.

The most basic approach is a shafted encoder in which a bearing connects the rotor with the frame. A shafted encoder must be coupled to the non-load-bearing end of the motor shaft, or to a gear box/measuring wheel. Shafted encoders tend to be very robust and work best for heavy loads. That said, bearings are vulnerable to failure, particularly in high-contamination applications. Sealing a bearing raises the same challenges as general IP ratings (below), with the addition of a need for grease or lubricants. Failure is not a matter of if, but a matter of when, which means that bearing designs may not be the optimal choice for high-reliability applications.

Hollow-shaft encoders are somewhat simpler and more robust than shafted designs. As the name suggests, hollow-shaft encoders sport a hollow shaft that can be fitted over the motor shaft (or any rotating shaft) with a pressure connection. They essentially automatically align themselves to the machine's rotating element, eliminating the need for brackets, bolts, and couplers, components that can add $70 or more to the bill of materials and also increase maintenance requirements. Closely follow your manufacturer's guidelines for tether installation, and hollow-shaft encoders become an easy and robust way to add rotary feedback to your system.

For applications that demand maximum reliability, a bearingless encoder might be a better option. A bearingless encoder basically lets the motor act as the mount for the two components of the system. The sensor unit connects to the motor shaft and the housing connects to the motor housing. The two elements of the device couple inductively, allowing the motor bearing to perform the function of the encoder bearing. This removes a point of failure while decreasing maintenance, weight, and size. Bearingless encoders are a good fit for low-load applications such as the ones found in many paper and steel mills.

In general, form factor plays a key role in feedback selection. On a factory floor, square footage correlates to money and machine builders are always eager to pack as much performance into the smallest space possible. Particularly in the case of a retrofit, space is an essential consideration. After all, you can't upgrade to a new component if it won't fit.

The mechanical constraints of the system also come into play. Make sure you understand the characteristics of the shaft to which you're mounting the encoder. What's the diameter? How much run out is there? How much endplay? Will the system be subject to thermal swings? If so, you need to either account for that or work with thermally invariant materials. One blindingly obvious error that has tripped up more than one design engineer is a simple failure to ensure that the encoder follows the measurement convention of the rest of the machine, whether metric or English.

The question of mechanical tolerances brings us back to the issue of trade-offs. High-performance designs require more exacting installation to operate properly. More forgiving designs can speed installation and maintenance, but the trade-off is performance. If an application requires accuracy and resolution above all, for example for a precision motor spindle application, you will need to be prepared to put more time, effort, and money into the design and installation process. If your goal is simply to keep an old motor running on a veteran machine, choose a low-performance product that will provide the greatest latitude during integration and operation. A technician with only minimal training can install a user-friendly component like a **NorthStar RIM Tach 8500** in a matter of a few minutes using a crescent wrench and a few other simple tools. The **Dynapar F-series** encoder, on the other hand, is designed to go on the inside of a servo motor rather than on the outside of an industrial motor. It carries only a minimal IP rating. It delivers high performance but achieving that performance requires careful installation by a skilled design engineer. Once again, the demands of the application, right down to staffing, determine the best choice for the system.

Speaking of IP ratings…

Defined by the International Electrotechnical Commission's IEC 60529 standard, the ingress protection rating is a two-digit system that describes an enclosure's ability to protect against solid objects ranging from fingers to dust, and liquid incursion varying from occasional drips of moisture to prolonged exposure to high-pressure fluid jets. With the proper IP rating, even an optical encoder can function effectively in a variety of punishing environments like shop floor and food processing plants.

As always, there are trade-offs. The higher the IP rating, the greater the attention paid to seals and coatings. Instead of a simple gasket, the system might involve multiple levels of interlocking flanges combined with complex seals, which can drive up cost and increase size. Another important point to keep in mind is that, in general, sealing strategies tend to be optimized for a specific type of contamination. The seal that works well to prevent liquid incursion, for example, probably doesn't effectively screen out particulates. A seal that can keep out even the finest dust remains vulnerable to high-pressure water jets. The component designed to do both probably won't function well at either. Beyond that lies the threat of failure – as before, it's not a matter of if, it's a matter of when. Unless your application cannot function without the resolution delivered by an optical encoder, if the environment is dirty, the application is generally best served by a magnetic design.

Without feedback, a motion system is unlikely to function as required. Fortunately, the motion control industry offers a wide range of technologies sure to fit any application. Make the right decision and you'll have a forgiving system that will deliver the performance you need and the lifetime you want. Make the wrong choice, and at best you'll have poor results, at worst, early failure. It all comes down to doing your homework. Study your application, understand your options, and use best practices to narrow down your choices, then work with your vendor to finalize the selection.

*Dynapar offers the world's broadest range of encoders, resolvers and accessories for motion feedback control. For 50 years, the four brands of Dynapar have been providing innovative, customized system solutions for virtually any heavy-duty, industrial, servo, or light-duty application. Innovative products, designed your way, delivered when you need them—that's the Dynapar difference. Click **here** for more information.*

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